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VISUAL AND SPATIAL MENTAL IMAGERY: DISSOCIABLE SYSTEMS
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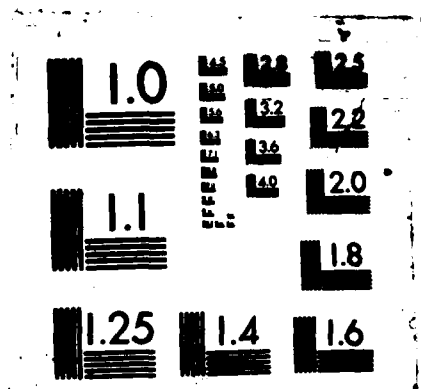
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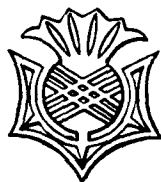
Visual and Spatial Mental Imagery:
Dissociable Systems of Representation

Martha J. Farah¹, Katherine M. Hammond¹,

David N. Levine², and Ronald Calvanio²

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The preparation of this report was supported by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract Number N00014-86-K-0094, Contract Authority Identification Number NR 170-0-1Y, as well as by NIH grants NS23458 and NS06209 and the Alfred P. Sloan Foundation.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION Unclassified		1b RESTRICTIVE MARKINGS	
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution unlimited.	
2b DECLASSIFICATION/DOWNGRADING SCHEDULE		4 PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report ONR-87-15	
6a NAME OF PERFORMING ORGANIZATION Carnegie Mellon University		6b OFFICE SYMBOL (If applicable)	
6c ADDRESS (City, State, and ZIP Code) Department of Psychology Pittsburgh, PA 15213		7a NAME OF MONITORING ORGANIZATION Personnel and Training Research Programs Office of Naval Research (Code 1142PT)	
8a NAME OF FUNDING SPONSORING ORGANIZATION		8b OFFICE SYMBOL (If applicable)	
8c ADDRESS (City, State, and ZIP Code)		9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-0094	
		10 SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO 61153N	PROJECT NO RR04208
		TASK NO RR042081	WORK UNIT ACCESSION NO 170-0-1Y
11 TITLE (Include Security Classification) Visual and spatial mental imagery: Dissociable systems of representation			
12 PERSONAL AUTHOR(S) Farah, M. J., Hammond, K. H., Levine, D. N. and Calvanio, R.			
13a TYPE OF REPORT Technical	13b TIME COVERED FROM _____ TO _____	14 DATE OF REPORT (Year, Month, Day) August 7, 1987	15 PAGE COUNT
16 SUPPLEMENTARY NOTATION			
17 COSA CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD 05	GROUP 09	SUB-GROUP	
		Visual cognition, mental imagery, neural bases of cognition.	
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20 DISTRIBUTION AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED UNLIMITED <input checked="" type="checkbox"/> SAME AS REPORT <input type="checkbox"/> OTHER SPEC		21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL Dr. Susan Chipman		22b TELEPHONE (Include Area Code) (202) 696-4318	22c OFFICE SYMBOL ONR 1142PT

Abstract

We argue that the debate over whether mental images are visual or spatial representations is based on the false premise that they must be one or the other. In support of the hypothesis that mental imagery has distinct visual and spatial components of representation, we (1) point out a correspondence between the notions of visual appearance and spatial location representations in visual neurophysiology, on the one hand, and the notions of visual and spatial representations as used in the debate about mental imagery, on the other; and (2) present the performance of a brain-damaged patient with impaired visual appearance representations on a variety of tasks used by cognitive psychologists on one side or other of the visual vs. spatial imagery debate. The patient is severely impaired on tasks previously used to argue for the visual nature of imagery, but performs normally on tasks previously used to argue for the spatial nature of imagery. This implies that the two groups of tasks tap distinct types of representation, which are neurologically dissociable and hence comprise functionally independent subsystems of imagery representation.

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INTRODUCTION

Much of the early history of research on mental imagery was concerned with the format of mental images. The principal issue was whether images are "analog," "array format" representations or whether they are "propositional" or "descriptive" in format (see Pinker, 1985 for a recent discussion of the format of mental images). Currently, there is fairly widespread agreement that that images represent some of the spatial properties of visual stimuli in an analog format (although dissenters certainly exist: see Pylyshyn, 1984). This view of imagery, while clearly a contrast to the propositional view, is sufficiently general that several more specific positions can be accommodated within it. One issue that divides researchers who hold the "analog" view of imagery is whether images are best characterized as visual or spatial representations. For example, in a recent introduction to imagery research, Kosslyn (1983, p. 77) states that "It seems clear that some of the same mechanisms are involved in both vision and visual imagery," whereas Anderson's cognitive psychology text (1985, p. 95) states that "[Images] are not tied to the visual modality, but seem to be part of a more general system for representing spatial and continuously varying information." In this paper we address the issue of visual and spatial representation in imagery using neuropsychological data.

"Visual" and "spatial" representation. To understand what is meant by visual and spatial representation in the context of this debate it is helpful to review the kinds of evidence that have been taken to be relevant to the issue. Several different types of research strategies have been used in arguing for either visual or spatial representation in imagery, and from these research strategies one can reconstruct operational definitions of visual and spatial representation. One way of distinguishing between visual and spatial representations is in terms of modality specificity. Visual representations are by definition specific to the visual modality, whereas spatial representations are not. This distinction has

given rise to a line of experimentation using selective interference paradigms. Segal and Fusella's (1970) experiment on visual and auditory imagery is one of the best known examples of a selective interference experiment in imagery research. They asked subjects to form and hold either visual images or auditory images while the subjects were engaged in visual and auditory signal detection. Imaging interfered more with same-modality signal detection than other modality signal detection, and this was taken to imply that, in the case of visual imagery, visual perceptual representations were being engaged. However, a different conclusion about the nature of imagery came from Baddeley and Lieberman's (1980) selective interference experiment. They had subjects perform an imagery task with two different secondary tasks: one which was visual but not spatial (discriminating the brightness of two lights) and one which was spatial but not visual (tracking a moving sound source with hand movements). Their imagery task involved constructing and maintaining an image of a path through a two-dimensional matrix, given a starting position in the matrix and instructions to move left, right, up or down. Baddeley and Lieberman found that the nonvisual spatial task interfered with the imagery task, whereas the nonspatial visual task did not, implying that imagery engages amodal spatial representations.

A second experimental strategy that has been used to address the modality-specificity of imagery has been to compare the imagery processes of sighted and congenitally blind subjects. Congenitally blind subjects would be expected to have spatial representations from their tactile interactions with the world, but would not be expected to have visual representations, having never seen. The logic of this research is that, if congenitally blind subjects perform normally on imagery tasks, then imagery tasks must engage spatial representations, not visual representations. Among the imagery tasks that have been used with congenitally blind subjects are mental rotation tasks (Carpenter & Eisenberg, 1978; Marmor & Zabeck, 1976), mental scanning tasks (Kerr, 1983), imagery mnemonic tasks (Jonides, Kahn & Rozin, 1975; Kerr, 1983; Zimler & Keenan, 1983) and semantic information

retrieval under imagery instructions (Kerr, 1983). For imagery tasks that normally require visual stimuli these researchers devised tactile analogs, such as mental rotation of palpated block letters or mental scanning of a palpated relief map. The general finding that emerges from these studies is that congenitally blind subjects are able to perform these mental imagery tasks and furthermore, their patterns of response time are qualitatively similar to those of sighted subjects, suggesting that both groups of subjects are using the same types of representations to perform the tasks. This implies that visual information per se is not an essential aspect of imagery.

Another way of distinguishing visual from spatial representations is based on the inclusion of intrinsically visual information, of which color is the prime example. Finke and Schmidt (1977, 1978) found perceptual aftereffects of imagined line orientation but not imagined color, consistent with the idea that images are spatial and not visual. In contrast, Intons-Peterson (note 1) has found that the color of an image has functional consequences. With eyes open, subjects require less time to form an image when the color of the image matches the color of the perceptual surface on which the image is projected. This implies that imagery is visual, in the sense of encoding intrinsically visual information in a form in which it interacts with perceived visual stimuli.

In addition to properties such as color that can only be encoded visually, some researchers have identified properties that are unlikely to have been encoded through any modality other than vision and have used these to address the issue of whether imagery is visual. For example, knowledge of the precise shapes and sizes of objects that one has seen but never touched is presumably represented visually. Many of Kosslyn's experiments (e.g. 1975) involve the retrieval of visual form information that is unlikely to have been encoded through other modalities, for example the sizes and shapes of zoo animals' body parts. Indeed Kerr (1983) was unable to use animal body-part imagery questions with her congenitally blind subjects, and attributed this to the subjects' lack of familiarity with this

type of information, as it is unlikely to have been encoded any way other than visually (p. 269).

Visual representations have also been distinguished from spatial representations based on their perspective properties, such as foreshortening and occlusion. Several studies have addressed the issue of visual versus spatial representation in imagery by determining whether or not images have perspective properties, that is, contain just the information about spatial relations available in the surface appearance of an object or scene. The alternative possibility is that images contain more abstract information about the spatial relations among the elements of the image, including information not available from any single vantage point. Thus, the finding that subjects can mentally rotate objects in depth as quickly and accurately as in the picture plane (Shepard & Metzler, 1971) even though the appearance of an object undergoing a depth rotation changes in much more complex ways than the appearance of an object undergoing a picture-plane rotation, is taken as evidence for the spatial nature of imagery. As Hinton (1979) has pointed out, if subjects were rotating visual representations, they would have to carry out additional foreshortening and hidden line removal operations in depth rotation which would not be required during picture plane rotation. Image scanning is another type of mental image operation which seems to involve perspectiveless spatial representations: Pinker (1980) has shown that subjects scan mental images of three-dimensional scenes equally quickly in all three dimensions, and that the time to scan between two objects is linearly related to their three-dimensional separation rather than their separation in a two-dimensional picture plane projection.

The role of perspective properties in imagery has also been explored in the context of imagery mnemonics in paired associate learning. Neisser and Kerr (1973) and Kerr and Neisser (1983) have found that the mnemonic effectiveness of images in paired associate learning is undiminished when one of the two associates is present in the image but occluded by the other associate. For example, an image of a harp sitting inside the statue

of liberty's torch was as effective in facilitating the later association of harp and torch as an image of the harp on top of the torch. They interpret this as supporting the idea that images represent the "layout" of objects in space, rather than the projective view of those objects that meets the eye.

In sum, visual representations are taken to be modality-specific representations that encode the literal appearance of objects, including perspective properties, color information, and aspects of form not available through touch or other modalities. Spatial representations are taken to be relatively abstract, amodal or multimodal representations of the layout of objects in space with respect to the viewer and each other.

Both visual and spatial imagery? A basic assumption in the debate over whether imagery is visual or spatial is that it is either visual or spatial. That is, the intent of most of the research reviewed above is not to demonstrate that imagery has some visual properties or some spatial properties, and that different tasks call upon one component of the imagery system or the other. Rather, the general aim of research in this area has been to demonstrate an apparently more parsimonious conclusion, that imagery is either just visual or just spatial. Accordingly, researchers on each side of the issue have tried to give alternative accounts for the other side's demonstrations. For example, Kosslyn (1980, chapter 2) presents a lengthy methodological critique of Neisser & Kerr's (1973) study of the mnemonic effectiveness of occluded images. He also attempts to account for three-dimensional mental rotation phenomena using a two-dimensional "visual buffer" representation (Kosslyn, Pinker, Smith & Schwartz, 1979). Similarly, Neisser (1976, chapter 7) has offered alternative interpretations of many demonstrations of visual properties of images (e.g., Ross, 1975; Segal & Fusella, 1970) in terms of visual expectations engendered in the subject by imaging, rather than the existence of an internally-generated representation of visual appearance.

In this paper it will be argued that different mental imagery tasks call upon different

kinds of imagery representations, some of which are visual and some of which are spatial, in the senses of "visual" and "spatial" discussed above. In effect, imagery researchers have been misled by the use of a common term, "imagery," to label what are in fact two distinct types of representation. Although this would certainly resolve the apparently conflicting results obtained by the "visual" and "spatial" camps, at first glance the idea seems unparsimonious. However, there is neurophysiological evidence that normal vision involves parallel, independent systems of visual and spatial representation. Given this evidence for the existence of both visual and spatial representations, the claim that imagery might also involve these two types of representations seems less extravagant. In fact, in the context of a "levels of perceptual equivalence" view of imagery (Finke, 1980), it seems quite natural that the structure of imagery would parallel this two-component structure of vision.

Before presenting the results of our neuropsychological case study, which provides evidence for the existence of distinct visual and spatial imagery systems, we will briefly review the neurophysiological and neuropsychological evidence for a distinction between visual and spatial representations of visual stimuli in perception.

The concept of "two cortical visual systems." Ungerleider and Mishkin (1982) coined the term "two cortical visual systems" to capture a distinction between two functionally and anatomically distinct systems of visual representation, one concerned with the appearance of individual objects and the other with the location of objects in space. They and other researchers (e.g. Pohl, 1973; Iwai & Mishkin, 1968; Brody & Pribram, 1978) have observed a marked contrast between the effects of parietal and temporal lesions in visual discrimination tasks: Monkeys with lesions in the parietal cortex are unimpaired in tasks that require visual discriminations on the basis of objects' appearances, but are grossly impaired in tasks that require assessing objects' spatial relations, such as reaching for objects or judging which of two objects is closer to a landmark. Lesions of certain regions of the parietal lobe also lead to a "neglect" of stimuli occurring in certain regions of space.

whether the stimuli be visual or tactile (Rizzolatti, Gentilucci & Matelli, 1985). In contrast, monkeys with lesions in inferior temporal cortex are unimpaired on the spatial tasks that the parietal-lesioned monkeys fail, but are grossly impaired at learning to discriminate between different forms, patterns and objects. Ungerleider and Mishkin called the system that represents visual appearance, located in the temporal lobes, the "what" system, and the system that represents spatial layout, located in the parietal lobes, the "where" system.

Data from single neuron recordings also support the distinction between representations of appearance in the temporal lobe and representations of spatial location in the parietal lobe: Temporal recordings have revealed neurons that respond to the shape and color of stimuli, including the three-dimensional perspective from which an object is viewed (e.g. Desimone, Albright, Gross & Bruce, 1984), whereas parietal recordings have not revealed such sensitivities (Robinson, Goldberg & Stanton, 1978). In contrast, parietal recordings reveal more sensitivity to the motion of a stimulus and its position relative to eye fixation than do temporal recordings (Lynch, Mountcastle, Talbot & Yin, 1977; Mountcastle, Anderson & Motter, 1981; Robinson et al., 1978; Sakata, Shibutani & Kawano, 1983).

There is clinical evidence that this rather counterintuitive division of labor in the monkey visual system also holds for the human visual system. Neurologists studying patients with bilateral posterior brain lesions recognized early in this century that impairments in the identification of visual stimuli (the visual agnosias) could occur independently of impairments in their spatial localization (Potzl, 1928; Lange, 1936). Patients with a rare combination of bilateral inferior temporal and occipital lobe damage and intact parietal lobes may be unable to recognize visually presented objects, despite adequate elementary visual abilities (e.g. visual sensitivity, acuity). These "agnosic" patients, like temporal-lesioned monkeys, have lost their internal representations of the visual appearances of objects, and thus cannot name or in other ways indicate their recognition of visually presented objects. Also like temporal-lesioned monkeys, these patients are able to represent the positions in space of visually

presented objects: they can point to objects, describe their positions with respect to one another in three dimensions, and draw accurate maps representing the layout of objects in space (see, e.g., Bauer & Rubens, 1985). Patients with bilateral parietal disease, like parietal-lesioned monkeys, are able to recognize visually presented objects, but are unable to localize stimuli, even the same stimuli that they are able to recognize. That is, such patients would be able to name a wrist-watch or paper clip held by an examiner at some location in their visual field, but when asked to point to or describe the location of this stimulus they would be grossly inaccurate (De Renzi, 1982; Ratcliff, 1982). A dissociation between relatively milder visual and spatial impairments has also been observed in unilateral right hemisphere-damaged patients, with visual impairments associated with right temporal damage and spatial impairments associated with right parietal damage (Newcombe & Russell 1969; Newcombe, Ratcliff & Damasio, 1987).

In summary, there exists evidence that in animals and in humans the representation of the visual appearance of stimuli and the spatial location of stimuli are subserved by distinct independent systems. For present purposes, the anatomical separateness of these two systems is of less importance than their functional independence -- the fact that each one can continue to function in the absence of the other. It is a fact about the functional architecture of vision that the visual appearances of objects and their spatial relations are represented separately and independently by two different perceptual systems.

On the basis of our clinical observations of two patients and a review of the neurological literature for similar cases, we have argued that the same distinction between the representation of visual appearance and spatial relations exists in mental images as in perception (Levine, Warach & Farah, 1985). That is, patients who are impaired in the recognition but not the localization of visual stimuli do poorly at describing and drawing objects' appearances from memory but can describe and draw the spatial layouts of objects and scenes from memory. Similarly, patients who are impaired in the localization but not

the recognition of visual stimuli do poorly at describing and drawing the spatial layout of objects and scenes from memory, but can describe and draw objects' appearances from memory. In the present paper we will relate these clinical observations more directly to the debate in cognitive psychology over whether imagery is best characterized as visual or spatial, by presenting the performance of a patient with impaired visual object recognition and intact object localization on a set of imagery tasks adapted from the cognitive psychology literature. The dissociation between this patient's performance on imagery tasks borrowed from the "visual imagery" camp and imagery tasks borrowed from the "spatial imagery" camp supports a direct correspondence between the visual versus spatial distinction in visual neurophysiology and the visual versus spatial distinction in the cognitive psychology debate about mental imagery. It will be argued that the dissociation in this patient's visual and spatial imagery abilities implies that imagistic representation, like perceptual representation, is not an undifferentiated faculty, but rather consists of at least the two independent sets of representational abilities, visual and spatial. Thus, the argument over whether imagery is visual or spatial is based on the false premise that is one or the other in fact, each type of representation exists and is necessary for a different subset of imagery tasks.

METHODS

Subject information. The brain-damaged subject, L.H., is a 36 year old minister currently working towards a second Master's degree. When he was 18 years old, he sustained a severe closed head injury in an automobile accident. Brain damage from the accident and subsequent surgery involved both temporo-occipital regions and the right inferior frontal lobe, as demonstrated by CT scan, neurological examination and surgical records. The bilateral posterior inferior temporal injury, with relative sparing of the parietal regions constitutes a rare configuration of brain damage that is generally associated with visual

agnosia. Details of L.H.'s medical history are published elsewhere (Levine, Calvanio & Wolf 1980; Levine et al., 1985).

L.H. made a remarkable recovery from his accident, eventually returning to the ivy-league college in which he was enrolled to complete his Bachelor's degree and going on to earn a Master's degree. When tested on the Wechsler Adult Intelligence Scale seven years after his accident, his verbal IQ was 132 and his performance IQ was 93. His memory quotient on the Wechsler Memory Scale was 121. He had no detectable language or motor skill deficits. His spatial localization of visual stimuli was normal, and his elementary visual capabilities were basically intact: Acuity was 20/50 in the left eye and 20/70 in the right with blindness in the peripheral visual field, particularly in the upper left and lower right quadrants of the visual field. Despite his general intellectual and elementary visual capabilities, L.H. was and still is profoundly impaired in visual recognition. He is unable to recognize live or photographed faces, and has great difficulty recognizing complex stimuli such as plants, animals, makes of automobiles and some foods. He also has some difficulty with photographs and drawings of common objects.

In the tasks described below, L.H.'s performance is compared with a control group of 12 men in their mid-30's with Master's degrees (mean age 35, range 33 - 38) who volunteered to participate for pay.

Visual and spatial imagery tasks. Subjects were given a variety of tasks tapping visual and spatial information in imagery. Our strategy was to administer imagery tasks from the cognitive psychology literature that are either similar or identical to the tasks that have been used by researchers on one side or the other of the "visual vs. spatial" issue in order to make contact as directly as possible with that issue as it has been studied in cognitive psychology.

In general, the spatial imagery tasks have been more thoroughly validated than the visual imagery tasks. That is, researchers who have used the spatial tasks have shown

empirically, that these tasks involve spatial representations per se, by the criteria discussed in the introduction. In contrast, researchers using the visual tasks have generally relied on the logical inference, that if a task involves representing information that could only be visually encoded (e.g. color, and the precise sizes and shapes of objects familiar by sight but not normally touched) then the task must involve visual imagery. We have not attempted to provide more thorough validation of these tasks than already exists. We selected four visual imagery tasks involving information about object appearance such as relative size, shape, and color, and seven spatial imagery tasks, three involving information about the relative locations of objects and four involving spatial transformations of objects. The only task that has figured prominently in the "visual vs. spatial" imagery debate that we have not used here is paired-associate learning with imagery mnemonics, because of mixed findings implicating both visual and spatial components (e.g. Baddeley, Grant, Wright & Thomson, 1975; Byrne, 1974; Kerr & Neisser, 1973; Neisser & Kerr, 1983; and Zimler & Keenan, 1983 have found evidence of spatial representation; Atwood, 1971; Janssen, 1976; Keenan & Moore, 1979 and Pavio & O'Keefe, 1971 have found evidence of visual representation; and Beech, 1984, has found evidence of both visual and spatial representation).

VISUAL IMAGERY TASKS

Color. Color is an intrinsically visual property and questions about the colors of objects often occur in experiments on visual imagery (Eddy & Glass, 1981; Kosslyn & Jolicoeur, 1980; Heuer, Fischman & Reisberg, 1986). We selected 20 common items that have characteristic colors but are nevertheless not verbally associated with their colors, for example a football. These objects were read to the subject and his task was to name the characteristic color of each one.

Size comparison. Another type of question used by researchers in the "visual" camp

involves comparing the sizes of similar-sized objects (e.g. Kosslyn, Murphy, Bemesderfer & Feinstein, 1977; Holyoak, 1977). It is claimed that subjects must use visual imagery when the sizes are similar, although imagery is not necessary when comparing the sizes of different-sized objects. The present task involved judging which of two similar-sized items was bigger, e.g. a popsicle and a pack of cigarettes. Sixteen pairs of common, inanimate household items were selected.

Animal tails. Judging or classifying the shapes of objects and parts of objects is a common visual imagery task. Animals and their body parts are often used in these tasks (e.g. Kosslyn, 1975, 1976) because one generally does not have nonvisual experience that would tell one whether, for example, a kangaroo has a long tail, and such facts are rarely explicitly encoded in verbal memory (cf. Kerr, 1983). We selected 20 animal names that were not verbally associated with tails (e.g. we did not use rats, beavers or peacocks) and asked subjects to respond whether or not the animals had long tails, proportional to their body size. As a control task to verify that subjects were familiar with the animals in the task and had general, nonvisual knowledge of these animals, we also asked them to judge whether the animals were native to the state in which the subject resided (which for L.H. was Massachusetts and for the control subjects was Pennsylvania).

State shapes. Shepard & Chipman (1970) found that subjects' ratings of the shape similarity between pairs of imagined states were highly similar to their ratings of shape similarity between pairs of visually-presented states. They concluded from this that the representations accessed by subjects when recalling shape information from memory were "second-order isomorphic" to the representations of shape engendered by seeing the same shapes. In the present task, subjects were given 20 triads of state names, and were instructed to circle the two in each triad which were most similar in their outline shape. A related task, testing spatial imagery in the same knowledge domain, consists of circling the pair of states within a triad that are closest. This is described more fully in the next

section.

SPATIAL IMAGERY TASKS -- IMAGE TRANSFORMATIONS

Letter rotation. Cooper and Shepard (1973) found that subjects must mentally rotate letter forms to an upright position before they are able to judge whether the letters have been printed normally or as mirror images. Mental rotation has been claimed to involve spatial representations, and indeed Cooper and Shepard (1973, p. 84) have said of the representations involved in the present task that "to classify these representations as purely visual images would be misleading. We should rather refer to them, more abstractly as spatial images..." Five asymmetrical capital letters (F, G, J, K, and R) were presented four times each, twice normally and twice mirror-reversed. The letters were oriented at roughly 45, 90, 135 and 180 degrees of angular displacement from the upright. Subjects' task was to say whether each letter was normal or mirror-reversed.

Three-dimensional form rotation. Shepard and Metzler's (1971) demonstration that the rate of rotation of 3-D forms was the same whether the forms were rotated in the picture plane or in depth is one of the most compelling pieces of evidence in favor of abstract spatial representations in imagery. In this task, 34 pairs of Shepard and Metzler forms were to be judged same or different (mirror image). Half of the pairs required 30, 60 or 90 degrees of rotation, and half required 120, 150 or 180 degrees of rotation. Half of the required rotations were in the picture plane and half were in depth. Amount of rotation was somewhat confounded with dimensionality of rotation, such that only 6 of the 17 shorter rotations (30, 60 or 90 degrees) were in depth.

Mental scanning. In mental image scanning experiments, subjects focus their attention on one part of an image and then move it continuously from that starting position to another part of the image. Kosslyn, Ball & Reiser (1978) first developed the mental image scanning paradigm as a way of showing that mental images preserve metric spatial

information in an analog or array format. This finding is neutral with respect to the issue of whether images are visual or spatial, because both Kosslyn's "visual buffer" and more abstract spatial representations are considered to have an analog or array format. However, Pinker's (1980) finding that subjects' scanning times depended on the distance scanned in three-dimensions rather than in a two-dimensional projection, and Kerr's (1983) finding that congenitally blind subjects show similar linear scanning times for memory images of tactile scenes implies that the representations involved in image scanning are primarily spatial. The present scanning task was based on Finke and Pinker's (1982) paradigm which they found evoked spontaneous mental image scanning, whether or not subjects were instructed to scan. In the version used here, two dots were placed pseudo-randomly on either the left half or right half of a 3x5 inch index card, along with an arrow 3 to 4 inches away from the dot to which it points or comes closest to pointing. The subjects' task was to say whether or not the arrow pointed to one of the dots. Note that this task differs from Finke and Pinker's task in that the dots and arrow are presented simultaneously. This was necessary because L.H. was unable to maintain an accurate image of the dot pattern after it was removed. However, Thorndike's (1981) finding that subjects' patterns of reaction times did not differ as a function of whether they were scanning perceived or imagined displays implies that this change in procedure should not affect the process of interest.

Size-scaling. *The process of comparing the shapes of two stimuli presented simultaneously but at different sizes involves scaling the stimulus representations using a process that Larsen and Bundesen describe as "essentially position-wise: The [short-term] memory representation specifies a spatial arrangement of pattern elements (points or subpatterns), and the comparison is made with respect to particular positions in the field of view" (p. 1, emphasis theirs).* Our task was based on the work of Larsen and Bundesen. Random ten-point polygons, like those of Larsen (1985), were presented in pairs, one above the other. The polygons in a pair were either identical, or differed by being mirror images

of one another. One polygon was large (4.5 inches average width) and the other was small (1.75 inches average width). The subjects' task was to say whether the pair of figures had the same shape, disregarding size differences.

SPATIAL IMAGERY TASKS -- IMAGERY FOR SPATIAL LOCATIONS

Matrix memory. One of the clearest demonstrations of the spatial nature of imagery is Baddeley and Leiberman's (1980) finding, described earlier, that subjects' performance on an imagery task was significantly impaired by a nonvisual spatial secondary task but not by a nonspatial visual secondary task. In the imagery task used by Baddeley and Leiberman, the subject hears the numbers 1 through 8, accompanied by instructions about where each of these numbers should be placed in an imaginary four-by-four matrix. The starting cell of the matrix is always the leftmost cell in the second row down from the top. A typical trial would consist of "In the starting square put a 1; in the square to the right put a 2; in the square below put a 3; in the square below put a 4..." and so on. After hearing a sequence of eight such instructions, the subject must recall the path, using the same verbal format, e.g. "In the starting square put a 1..." Subjects in the present study were given 20 such eight-step sequences, which had been pre-recorded on tape.

Letter corner classification. In this task, a block letter with an asterisk next to the lower left corner is shown to the subject and then removed. The subject's task is to maintain an image of the letter and, beginning with the asterisked corner and travelling in a clockwise direction, classify the corners of the letter according to whether they are on the top or bottom of the letter (in which case the response is "yes") or whether they are from neither the top nor the bottom (in which case the response is "no"). After the letters E, L, M, N, W and Z have each been classified in this way, they are then presented again, with instructions to say "yes" for corners on the extreme right or left and "no" for the other corners. Brooks (1968) and Baddeley, Grant, Wight and Thompson (1975) have demonstrated that this task is susceptible to interference from concurrent visual/spatial tasks.

that is, tasks with both visual and spatial components. Brooks (1968, experiment 7) addressed the question of whether the interference was specifically visual, or more generally spatial, by assessing the interference from a secondary tactile/spatial task. The latter task interfered significantly with the letter corner classification task, leading Brooks to conclude that this imagery task involves representations that are spatial but not specifically visual.

State locations. The final spatial imagery task does not come directly from the cognitive psychology literature, but is included as a contrast with the state shape task in the visual imagery section. Subjects were given 20 triads of state names, and were asked to circle the two states in each triad that were closest to one another. Triads that could be correctly grouped on the basis of verbal associations to regions (e.g. two "southern" states and a "northern" state) were not used.

Order of tasks. The tasks were administered to L.H. on three separate days, the first and third of which included two separate testing sessions. The order of tasks in each session was: first (day 1, session 1) Animal Tails and Color; second (day 1, session 2) Size Comparison, Mental Scanning, and Size Scaling; third (day 2) Letter Rotation and Matrix Memory; fourth (day 3, session 1) Three-dimensional Form Rotation, Letter Corners, and fifth (day 3, session 2) State Shape and State Location. Normal control subjects were also tested individually. Seven subjects received all the tasks in one session (lasting about two and a half hours with a five minute break in the middle), three subjects received the tasks in two sessions on different days, one subject received the tasks on three sessions on three different days, and one subject received the tasks in four sessions on four different days. The tasks were given in the following order to all normal control subjects: Animal Tails and Color, Mental Scanning, Size Scaling, Letter Rotation, Matrix Memory, Size Comparison, Three-dimensional Form Rotation, State Shape, State Location, and Letter Corners.

RESULTS

The performance of L.H. and the twelve control subjects on each of the eleven tasks is shown in figures 1 and 2. These figures show a clear dissociation between L.H.'s performance on the visual imagery tasks, which is below normal (figure 1), and his performance on the spatial imagery tasks, which is normal (figure 2). We have quantified the extent to which L.H.'s performance may be considered abnormal in each of the imagery tasks by considering all thirteen subjects together and asking whether, on each task, L.H. is a statistical outlier.

In the tasks which require specifically visual imagery, L.H. was impaired. On the Colors task, L.H. was correct on only 10 of the 20 items. The average performance of the control subjects was 18.9 out of 20 items correct, with a standard deviation of .9. Considering the thirteen subjects together, L.H. is an outlier, with a z-score of -3.14, $p < .001$. On the Size Comparison task, L.H. was correct on 11 out of 16 items. The average performance of the control subjects was 14.9 out of 16, with a standard deviation of 1.0. Again, when all thirteen subjects are considered together, L.H. is an outlier, $z = -2.50$, $p < .01$. On the Animal Tails task, L.H. was correct on 13 out of 20 items. The average performance of the normal control subjects was 19.25 out of 20, with a standard deviation of .45. L.H. is an outlier, $z = -3.22$, $p < .001$. On the control task for Animal Tails judging whether the same animals were native to the subject's home state, L.H. was correct on 20 out of 20, and the average performance of the control subjects was 19.9 out of 20, with a standard deviation of .29. L.H. is not an outlier on this task, $Z = +.28$. This supports the claim that L.H.'s poor performance on the Animal Tails task is due to an inability to visualize the animals, and not a general lack of knowledge about the animals. On the State Shape task, L.H. was correct on 8 out of 20 items. The average performance of the control subjects was 14.4 out of 20, with a standard deviation of 3.65. L.H. is a borderline outlier here, $z = -1.51$, $p < .07$.

In contrast to his low performance on the visual imagery tasks, L.H.'s performance on the spatial imagery tasks is well within the range of the normal subjects' performance. For the image transformation tasks, L.H. performs better than the average normal control subject, although these differences are all nonsignificant. On the Letter Rotation task, L.H. was correct on 20 out of 20 items. The average performance of control subjects was 19 out of 20, with a standard deviation of 1.13. On the Three-Dimensional Form Rotation task, L.H. was correct on 34 out of 34 items. The average performance of control subjects was 30.5 out of 34 with a standard deviation of 2.84. On the Scanning task, L.H. was correct on 32 out of 32 items. The average performance of control subjects was 29 out of 32, with a standard deviation of 1.95. The Size-Scaling task was evidently too easy and produced ceiling effects, which prevent a meaningful comparison of L.H. and the control subjects. However, we can at least conclude that L.H. can perform size scaling, without being able to compare his proficiency to that of normal control subjects. L.H. was correct on 32 out of 32 items. The average performance of control subjects was 31.8 with a standard deviation of .39.

In the tasks requiring imagery for spatial locations, L.H. was again well within the range of normal performance. On the Letter Corner Classification task L.H. was correct on 10 out of 12 items. The average performance of control subjects was 6.25 out of 12 with a standard deviation of 3.0. On the Matrix Path Memory task, L.H. was correct on 18 out of 20 items. The average performance of control subjects was 18.17 with a standard deviation of 2.17. L.H. is not an outlier, $z = -.12$. On the State Location task, L.H. was correct on 17 out of 20 items. The average performance of control subjects was 17 out of 20 with a standard deviation of 2.59.

The only visual and spatial imagery tasks that permit a direct comparison are the state shape and state location tasks, as these two tasks were identical in format and in the general knowledge domain that they tested. For normal subjects, performance on the two

tasks were similar: The average normal subject's performance on state locations was 1.23 points higher than his performance on state shapes. In contrast, L.H. showed a spread of 9 points between these two tasks. Applying the same statistical analysis to the spreads between state location performance and state shape performance as was applied to the individual task performances, L.H. is again an outlier: $z=2.69$, $p<.001$.

DISCUSSION

L.H. shows a profound imagery deficit on certain imagery tasks, and yet does well on other imagery tasks. If we divide the imagery tasks into two groups according to whether L.H. can or cannot perform them, the resultant groups are exactly co-extensive with two groups of tasks used by researchers who have maintained that imagery is either spatial or visual, respectively. Furthermore, this coincidence of the two ways of grouping imagery tasks was predicted by neurophysiological considerations of the brain substrates of spatial and visual representation. We will first consider some alternative explanations of these results and then discuss the broader implications of the findings for the nature of mental imagery.

Is it possible that the spatial imagery tasks, on which L.H. performs well, are simply easier than the visual imagery tasks? If we had simply compared the absolute performance of L.H. on visual and spatial imagery tasks, this would indeed be a possibility. However, by comparing his performance on each task to that of a group of normal control subjects, the intrinsic difficulty of the tasks does not affect our conclusions. Easier or harder tasks will produce higher or lower levels of performance for both L.H. and the normal control subjects: what we have examined here is the performance of L.H. relative to the control subjects.

Is the visual/spatial distinction confounded with another distinction in our tasks, which is in fact the underlying cause of the observed dissociation in L.H.? The only plausible candidate for such a confounding factor that has occurred to us is the amount of long-term memory knowledge demanded in each of the tasks. The visual imagery tasks all draw upon

long-term memory knowledge, whereas most of the spatial imagery tasks do not. However, this alternative explanation is inconsistent with several aspects of the present results. First, there is a spatial imagery task whose demands on long-term memory knowledge are as great as the visual imagery tasks, namely the state location task. On this task, L.H. did better than the average normal control subject. In contrast, on a visual imagery task with the identical format, namely the state shape task, L.H. was impaired relative to the normal control subjects. This same dissociation is evident in the clinical assessments of L.H.'s visual and spatial memory imagery (Levine et al., 1985): He is able to draw maps and describe the spatial layouts of cities, neighborhoods and rooms from memory, but is unable to draw or describe the appearances of most objects from memory. Second, on a control task for one of the visual imagery tasks, which tested general long-term memory knowledge of the test items, L.H. was unimpaired: For the same animals whose tail lengths he could not recall, he was able to recall whether they were native to Massachusetts. Third, extensive neuropsychological testing of L.H. has failed to reveal any impairments in retrieving general knowledge or semantic memory, and only mild impairments in the acquisition of new memories. These considerations argue against the possibility that the apparent visual imagery deficit in L.H. is actually a memory deficit. In examining the relation between memory retrieval and visual and spatial imagery tasks it is clear that, in general, the spatial imagery tasks do weight image maintenance and manipulation more than visual imagery tasks, whereas visual imagery tasks weight information retrieval more than spatial imagery tasks. This is a generalization about the kinds of tasks that typically evoke the use of visual and spatial imagery in cognitive psychology experiments.

In considering alternative explanations of these results, we should also discuss the ways in which the single case study method might limit or distort our conclusions. The use of single cases, rather than groups of subjects, has recently come into favor in cognitive neuropsychology (Caramazza, 1984; Schwartz, 1984; Shallice, 1979). It is argued that if we

view brain damage as an "experiment of nature." each subject in any group will have undergone a different "experimental manipulation." and we risk basing our conclusions on average performance profiles which are in a sense artifactual as they do not exist in any one case. In contrast to the cognitive psychology approach of testing a *group* of subjects on *one* task, it is therefore preferable to study *single* cases across a *variety* of converging tasks. This approach is nowhere more called for than in the study of subjects with visual object agnosia, a condition that is both extremely rare and somewhat variable from case to case. The logic of single case study is that, if we can observe a dissociation between two abilities, tested in multiple ways in the same subject, then we can conclude that these two abilities do not rely on the same underlying cognitive system. The sense in which such conclusions are limited, by virtue of coming from a single case study rather than a group study, is that it is logically possible that the single case was anomalous before sustaining brain damage. In the present case, the danger is that L.H. might have an abnormally organized mental imagery system, and that other subjects perform both visual and spatial imagery tasks with the same cognitive system. Although this remains a logically correct possibility, it violates a basic assumption of cognitive science, which is that the large-scale architecture of cognition is fixed from one member of the species to another. Even the study of individual differences in cognition is based on the idea that individuals differ in the capacities of specific components of a common cognitive architecture, or in their strategic or habitual choice of which components to use for performing a particular task, not that the architecture itself differs from person to person. In the present case, L.H. was to all appearances psychologically and neurologically normal prior to his accident at age 47, and there is therefore no reason to suspect that he has an anomalous cognitive architecture.

In answer to the question "Is mental imagery visual or spatial?" the results of the present study say "both." Each side of the visual versus spatial debate has been correct in that mental imagery does involve both visual and spatial representations, but each side of

the debate has also been wrong, in that imagery is not exclusively visual or exclusively spatial. The fable of the blind men standing around an elephant and trying to describe it seems relevant here: They all disagree, one maintaining that an elephant is a long, dangling, snakelike beast, another saying that an elephant is a stout cylindrical creature planted firmly on the ground like a tree-trunk, another saying that elephants are big, floppy, roughly circular sheets of rough skin, and so on. Like the different positions of the blind men next to the elephant, the different sets of experimental tasks used by the two sides of the debate have each revealed only a limited aspect of the imagery system. This source of bias has been compounded by a desire for parsimony, leading us to believe that only one type of representation could underlie the range of abilities that we call imagery. However, whereas the difference in parsimony seems large when one considers the imagery system in isolation and asks whether it includes just one type of representation or two, the difference becomes much smaller when one considers the array of representations already known to exist in our cognitive architecture, and asks whether the imagery system engages just one of the available representations or two. Neurophysiological evidence suggests that our cognitive architecture includes both representations of the visual appearance of objects in terms of their form, color, and perspective, and of the spatial structure of objects in terms of their three-dimensional layout in space. The fact that an impairment of the visual appearance representations due to brain damage affects performance on just the imagery tasks used to argue for visual representation in imagery, and spares performance on the imagery tasks used to argue for spatial representation in imagery, implies that these two groups of tasks tap independent components of imagery representation, shared with vision and spatial perception respectively.

Figure Captions

Figure 1. Performance of L.H. (grey bars) and normal control subjects (white bars) on four visual imagery tasks. See text for descriptions of tasks. Error bars show one standard deviation above and below the normal subjects' means.

Figure 2. Performance of L.H. (grey bars) and normal control subjects (white bars) on seven spatial imagery tasks. See text for descriptions of tasks. Error bars show one standard deviation above and below the normal subjects' means.

Acknowledgements

This research was supported by ONR contract N0014-86-0094, NIH grant NS23458, the Alfred P. Sloan Foundation, and NIH program project grant NS06209-21 to the Aphasia Research Center of the Boston University School of Medicine. The authors thank Dr. M. J. Intons-Peterson for her many helpful comments on an earlier draft of this manuscript. We also thank L.H. for his help in this project.

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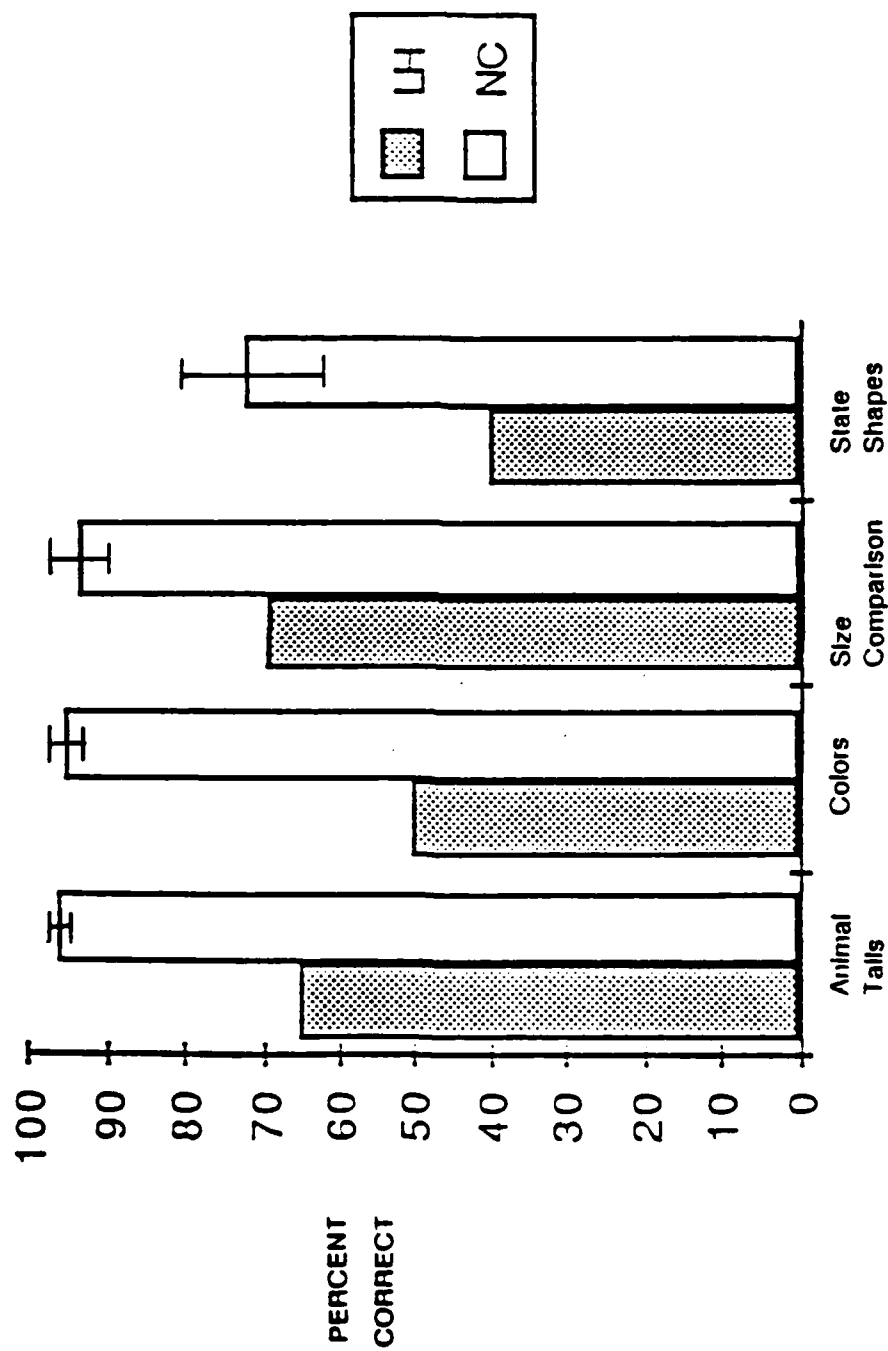
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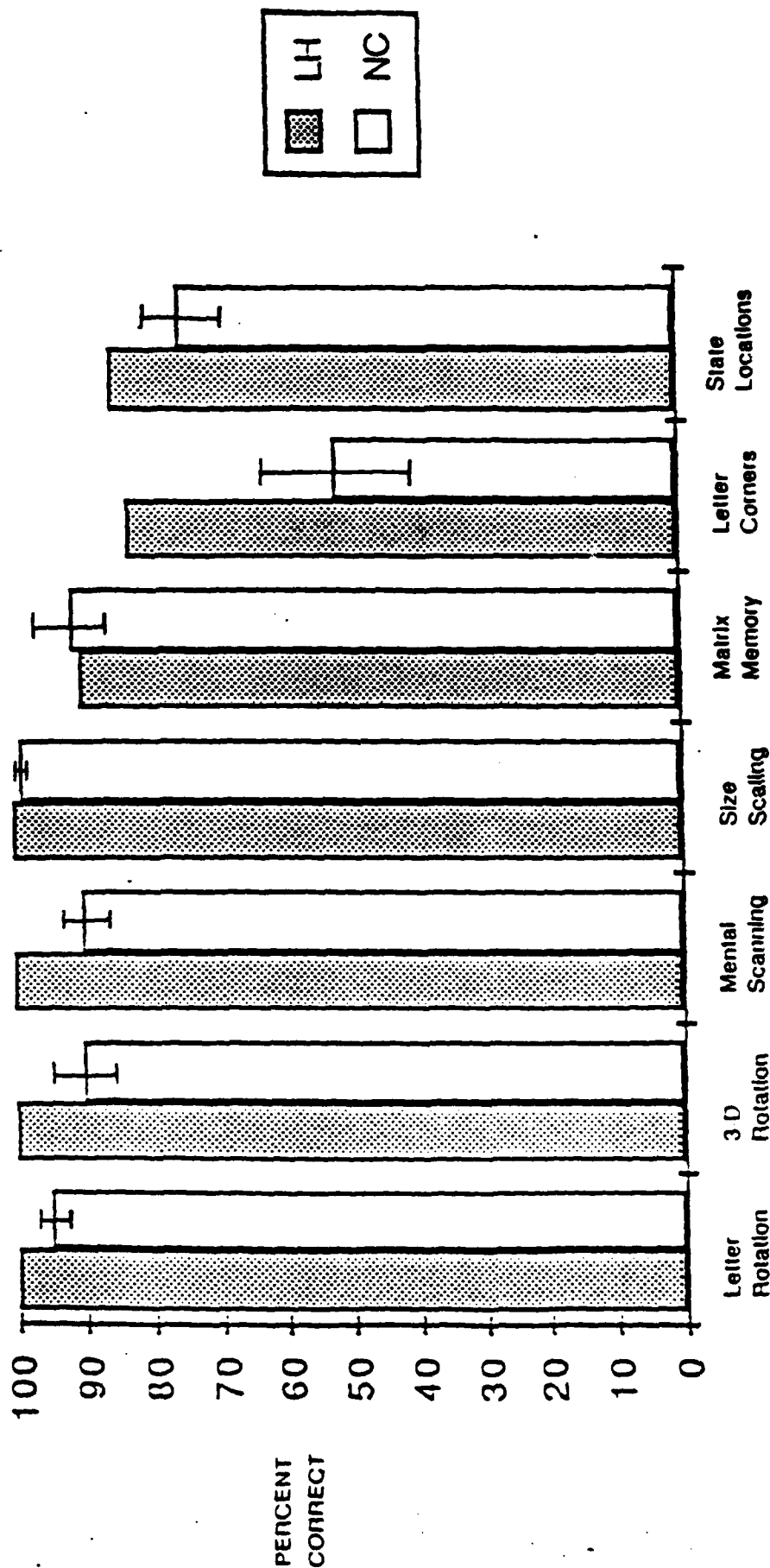
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"VISUAL" IMAGERY TASKS



"SPATIAL" IMAGERY TASKS



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